1. Science aim/goal

Search for biosignatures and measure climates in nearby terrestrial super-Earth exoplanets through transit emission spectroscopy.

2. (i) Scientific Importance:

One of the primary goals of the astrobiology community in particular, and the broader astrophysical and planetary science communities in general, is the detection of inhabited terrestrial extrasolar planets. Habitability is typically defined as the ability of a planet to sustain liquid water on its surface, which is a function of orbital distance but also depends upon atmospheric composition. Spectroscopic characterization of terrestrial planetary atmospheres will provide constraints for climate models to assess habitability. Furthermore, this remote characterization may provide evidence of spectroscopic biosignatures that indicate potentially biological interactions between atmospheric and surface processes.

At mid-infrared wavelengths, detection of terrestrial super-Earth exoplanets (1-3$R_\oplus$) orbing their host star at a separation of about 1-2 AU is possible through transit spectroscopy, which allows for observation of both the absoprtion (primary) and emission (secondary) spectra of the planet. Successful detection of planetary transits requires optimal alignment of the orbit from the observer's vantage. In the mid-infrared, the main observable is the emission spectrum of the planet, as measured in the secondary transit.

Mid-infrared transit emission spectroscopy of exoplanet atmospheres allows for detection of the prominent 15μm CO_2 band as well as the H_2O vapor continuum at ~18μm and longer wavelengths, thereby providing a direct measure of the greenhouse effect in exoplanets. These features alone can distinguish wet Earth-like planets from those that are dry more Venus-like with dense CO_2 atmospheres or Mars-like with thin CO_2 atmospheres (see Figure 1). Observation of the H_2O vapor continuum also provides a direct measurement of planetary radius, which can be inferred by comparing the mid-infrared color temperature to expectations from Planck's law and calculating the expected surface area, and thus radius. The strong bands of NH_3 beyond 30μm may represent our best chance at detecting nitrogen-bearing molecules in the atmospheres of habitable exoplanets. The strong band of ozone at 9.7μm will allow for detection of molecular oxygen, which combined with other out-of-equilibrium molecular specie, is a powerful biosignature. Other atmospheric constituents and possible biosignatures, such as the presence of N_2O, can also be detected at mid-infrared wavelengths.

Emission spectra of exoplanets are generally highly complementary to absorption spectra obtained at shorter wavelengths, as they do not depend on the scale height of the atmosphere, which is otherwise a degenerate parameter in primary transit observations.

(ii) Measurements Required:

In the mid-infrared, the main observables of transiting planets are the secondary transit emission spectrum, as well as the thermal phase curve of the planet. From simulations carried out for JWST, the emission signal from a cool super-Earth orbiting an K dwarf is 100 ppm at 10 micron, but rapidly increasing with wavelength (Greene et al. 2016). Super-earths orbiting M-dwarfs will be more favorable at several 100 ppm. If contrasts of 25 ppm can be achieved at 10-40 micron, high quality emission spectra can be obtained for such systems. The characterization of super-Earth exoplanet atmospheres through transit spectroscopy may require periodic observation of targets of interest over several orbital periods in order to obtain the required accuracy. Because most targets will likely be selected from TESS detections, the period of transiting planets will be known (although new planets may also be discovered in systems that harbor only one planet). Characterization of exoplanet atmospheres requires a stable spectrometer to identify key spectral features in the mid-infrared. The resolving power needed to fully resolve the key molecular bands is a few 100.

(iii) Uniqueness to 10μm to few mm wavelength facility:

Current and near-term characterization capabilities are limited in their ability to characterize the mid-infrared of exoplanet atmospheres. The FIRS can also detect water vapor continuum absorption at longer wavelengths, which can be used to calculate planetary radius. Furthermore, mid-infrared measurements could possibly provide direct measurements of emission from planetary surfaces at wavelengths where clouds are transparent.

(iv) Longevity/Durability:

The Far Infrared Surveyor would allow for high-precision follow-up observation and characterization by targets identified by TESS. The Transiting Exoplanet Survey Satellite (TESS) mission is scheduled to launch in December 2017. TESS will survey approximately 500,000 nearby stars and is expected to detect transits from about 3,000 systems. Of these, about 300 are expected to be super-Earths, about 30 the size of Earth, and a handful Earth-sized planets within the habitable zone. These exoplanet candidates will be ideal targets for follow-up observation and spectral characterization with the FIRS.

The James Webb Space Telescope (JWST) is scheduled to launch in October 2018. JWST will obtain high-quality transit spectroscopy of giant planets, and, with a large investment in observing time, will likely provide relatively low signal-to-noise spectra of a few super-Earths. However, it is limited to infrared wavelengths 12μm and shorter, which does not allow for efficient detection of cool (~300 K planets), detection of the CO_2 bending mode or NH_3 and N_2O features in the 10μm to 40μm range. The FIRS, given a larger aperture than JWST, and next generation instruments, may be capable of efficient emission transit spectroscopy of the atmospheres of a significant sample of cool rocky planets in a post-JWST world.

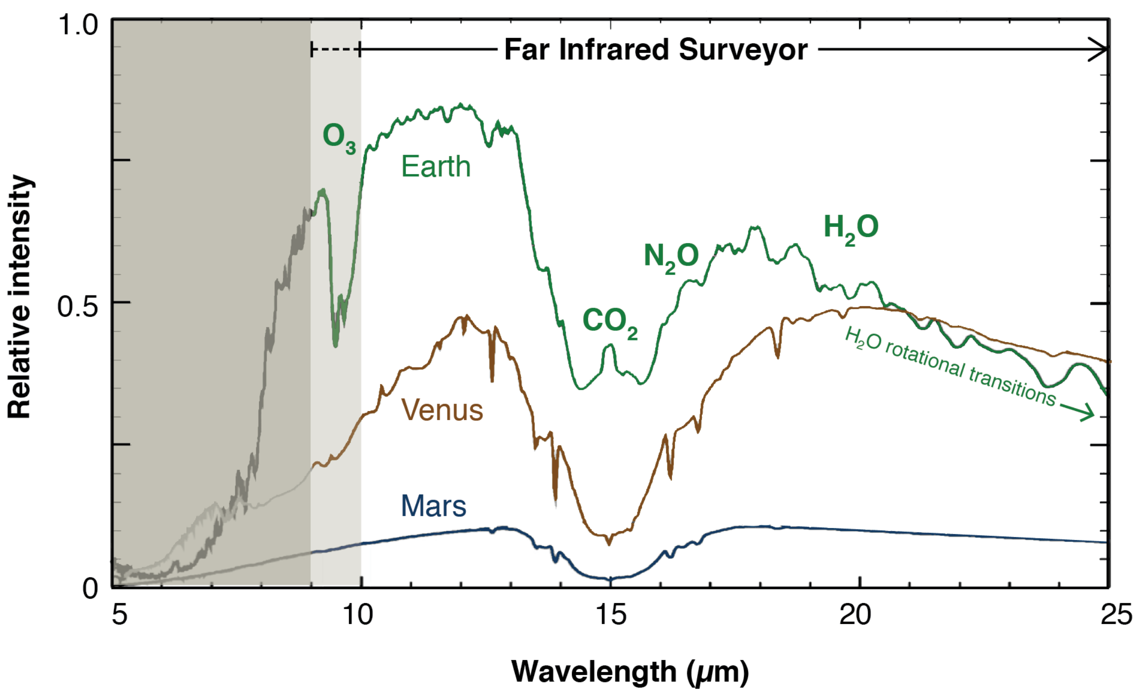

Figure 1: Relative intensity of emission as a function of mid-infrared wavelength for three modeled terrestrial planets. Bands for carbon dioxide, nitrous oxide, and water vapor can all be observed within the 10μm to ~25μm range. Ozone may or may not be visible, as the prominent feature occurs at ~9μm.

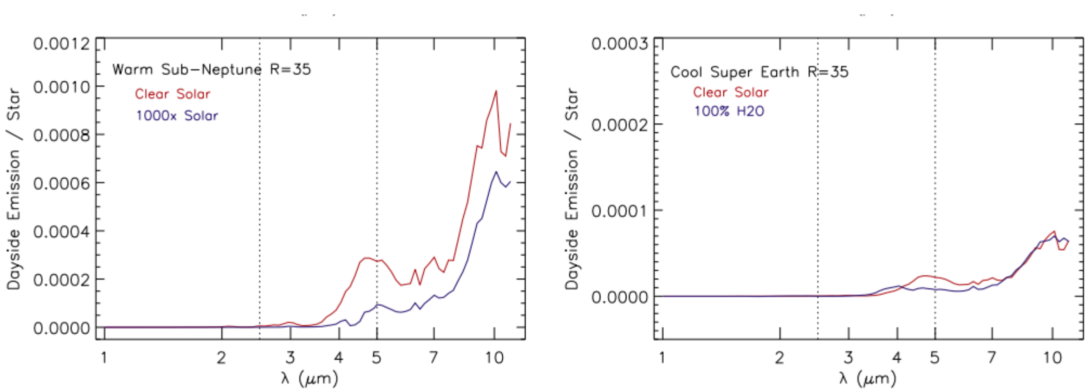

Figure 2: Models of emission contrast spectra for a sub-Neptune and a Super-Earth (Greene et al. 2016). Note the rapid increase in emission contrast in the mid-infrared, indicating the need for long-wavelength transit observations to take advantage of emission spectra from cool planets.

Table:

Parameter	Unit	Required value	Desired Value	Comments
Wavelength/band	μm	9μm to 40μm	5μm to 40μm	The required value range allows for detection of O3, CO2 and NH3. Expanding to shorter wavelengths includes CH4
Number of targets		30	100	The required value is based on the expected number of cool super-

				earths to be detected by TESS.
Angular resolution	arcsec	-	-	Transit spectroscopy is not limited by angular resolution
Spectral resolution	$\Delta\lambda/\lambda$	500		
Bandwidth		5 micron	30 micron	Needed to cover the CO_2 band. Desired value provides the full range in one observation.
Continuum Sensitivity (1 σ)	μJy	-		
Spectral line sensitivity (1 σ)	W m^{-2}	-		
Signal –to-noise		10	30-40	On isolated planetary emission spectrum. Desired value allows characterization of super-Earths orbiting M dwarfs
Cadence	minute	1	-	
Photometric Precision	ppm	25	15	JWST ~ 25, super-Earth emission contrast at 10-40 micron 100-500 ppm.

5. Key references:

Beichman, C., Benneke, B., Knutson, H., Smith, R., Lagage, P.O., Dressing, C., Latham, D., Lunine, J., Birkmann, S., Ferruit, P. and Giardino, G., 2014. Observations of transiting exoplanets with the James Webb Space Telescope (JWST). Publications of the Astronomical Society of the Pacific, 126(946), p.1134.

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